# Postoperative efficacy and safety of vessel sealing: an experimental study on carotid arteries of the pig

Stéphane V. Berdah · Christiaan Hoff ·
Peiman Hossein Poornoroozy · Peter Razek ·
Yves Van Nieuwenhove

**Abstract**

*Background*   The aim of this preclinical study was to analyze the burst pressure of large in vivo sealed vessels, not just immediately, but also in the first 7 postoperative days.

*Methods*   In 26 anesthetized pigs, the right carotid artery was sealed and cut using a novel device that integrates bipolar and ultrasonic energy. The animals were then awakened. They underwent a second surgical procedure after different follow-up periods ranging from 1 to 7 days: the left common carotid artery was sealed and cut in the same way as the contralateral artery. Perioperative and postoperative clinical events, evolution of burst pressure over time, and comparison between immediate and delayed burst pressure were analyzed.

*Results*   All sealings were successful. There were no perioperative or postoperative complications. Median immediate (day 0) burst pressure was 949 mmHg (IQR 781–1181). Burst pressure decreased postoperatively but was never below 500 mmHg in any pig.

*Conclusion*   Postoperative variations are observed in the burst pressure of in vivo sealed arteries. Immediate burst pressure alone should not be used for validating vascular sealing devices.

**Keywords**   Sealing and cutting systems · Sealing device safety · Sealing device efficacy

Laparoscopic surgical procedures have become more and more demanding. New surgical tools have facilitated these developments. Some of these tools are dedicated to vascular ligation and division using bipolar or ultrasonic energy. They are intended to avoid laparoscopic sutures and/or clip application. They also can reduce the number of surgical manipulations and even operating time. In any case, vascular sealing has to be definitive, even for large vessels. In order to test and/or validate new sealing devices, many experimental studies have measured the burst pressure of sealed vessels. All these studies tested immediate burst pressure after vessel sealing in vitro [1–10] or, more rarely, in vivo [11–19]. A burst pressure above 360 mmHg is considered a valid threshold for sealing safety, as it is three times the physiological blood pressure [16]. Although rebleeding is an uncommon but life-threatening postoperative event, there are no experimental data in the literature about the evolution of sealed vessels in the first few postoperative days.

The aim of this preclinical study is to analyze the evolution of burst pressure over the first 7 postoperative days of large vessels sealed in vivo using a novel device that integrates bipolar and ultrasonic energy.

## Materials and methods

### Animal care

All procedures were carried out to ensure respect for the European Convention on the protection of vertebrates used for experimental or other scientific purposes within the Centre d'Enseignement et de Recherche Chirurgical (CERC) at the Faculty of Medicine in Marseille, France. The experiment was carried out with the consent of the institution's Animal Ethics Committee.

S. V. Berdah (✉) · C. Hoff · P. H. Poornoroozy · P. Razek ·
Y. Van Nieuwenhove
Faculté de Médecine Nord, Aix-Marseille Université, CERC
(Centre d'Enseignement et de Recherche Chirurgical), CS80011,
51 Boulevard Pierre Dramard, 13344 Marseille Cedex 15, France
e-mail: stephane.berdah@ap-hm.fr

Twenty-six sows weighing approximately 30 kg were used for this study. The arrival of the animals was planned to be at least 48 h before the start of the experiment to allow them time to acclimatize to the new environment. A clinical examination was carried out at the end of the acclimatization period, and only animals in good health were chosen for the experiment. The animals were stabled in individual boxes with free and unlimited access to a water point and fed according to their weight. Feeding was suspended on the day before surgery.

### Design of study

A right common carotid artery ligation and division was carried out by means of a lateral cervicotomy in 26 pigs. This division was achieved using THUNDERBEAT® (Olympus Medical Systems Corp., Tokyo, Japan), a new surgical device that integrates bipolar and ultrasonic energy. This artery was chosen because it is one of the largest in this animal model, usually more than 5 mm in diameter. Moreover, its unilateral ligation does not usually have any short-term clinical consequences. The animals were then awakened and stabled in their individual boxes. Animals underwent a second surgical procedure after different follow-up periods ranging from 1 to 7 days. During this second procedure, the left common carotid artery was ligated and divided in the same way as the contralateral artery. Distal and proximal parts of the ligated left and right arteries were then harvested and the animal was killed. All ligations were made on circulating arteries with a beating heart. The objectives of this study were to assess the acute and chronic clinical efficacy and safety of these ligations and the evolution of burst pressure over time. Two measurements were studied: (1) the evolution of burst pressure over time during the first postoperative week, and (2) a comparison of burst pressure in six groups of pigs day 0 (D0) vs. D1, D2, D3, D4, D5, and D7. The sample size of each group was calculated so as to test a potential drop in burst pressure below $360 \pm 10$ mmHg (three times the physiological blood pressure), with $\alpha = 0.05$ and a power of 0.90.

### Surgical protocol

All the animals were premedicated with an intramuscular injection of azaperone (2 mg/kg) and ketamine (10 mg/kg) and then anesthetized with intravenous propofol (4 mg/kg) prior to orotracheal intubation. They were then ventilated mechanically at a frequency of 15/min. Anesthesia was maintained with propofol (0.2 mg/kg/min) and sufentanyl (1 µg/kg/h) using electrical syringe pulses.

The animal was laid out supine on the operating table and sterile drapes were applied after betadine preparation. A short right vertical lateral cervicotomy was then performed and the common right carotid artery was identified and checked for at

least 5 cm. It was then sealed and divided by a single application of THUNDERBEAT®. THUNDERBEAT® delivers both ultrasonically generated frictional heat energy and bipolar heat energy simultaneously by a single instrument. The artery was fully grasped in the center of the jaws of the instrument; the device was then activated with light tension on the vessel until the entire process of sealing and cutting was complete.

No drain was placed and the neck was closed in two layers. The animal was given a prophylactic dose of 0.5 g of cefoxitin. This antibiotic treatment was continued for 2 days at a rate of 1 g of cefoxitin morning and evening. Analgesics could be administered to the animal during the first few postoperative days if the veterinary surgeon considered it necessary.

### Data collection

All relevant perioperative and postoperative data were collected prospectively, including sealing time and any perioperative events (e.g., hemorrhage following ligation and division or type of additional hemostasis provided). Prospective clinical surveillance of the animals included behavior, temperature, neurological examination, defecation and urination, and aspect of the scar. The animals were reoperated on after different periods of time after surgery: 1 day six pigs, 2 days four pigs, 3 days four pigs, 4 days four pigs, 5 days four pigs, and 7 days four pigs.

The anesthetic protocol was identical to that of the initial operation. A short left vertical lateral cervicotomy was performed. The left common carotid artery was then identified and checked. It was ligated and divided by a single application of THUNDERBEAT®. Euthanasia was then performed by an intravenous injection of 3 g of KCl. Distal and proximal parts of left and right ligated common carotid arteries were harvested. Four sealed vessels per pig were obtained in this way.

All arteries were placed on tissue moistened with saline and immediate burst pressure testing was performed. Burst pressure of the sealed vessel was measured in the bench test (Fig. 1). Saline was infused into the artery through a catheter introduced into the open part of the vessel. The maximum pressure before leakage at the sealing site was considered the burst pressure. The diameter of the arteries was measured immediately after burst pressure measurement was complete.

### Statistical analysis

All data were plotted on a curve showing the evolution of burst pressure (mmHg) over time (days). Data are expressed as mean ± standard deviation (SD) or as mean and interquartile range (IQR) when indicated. The data on
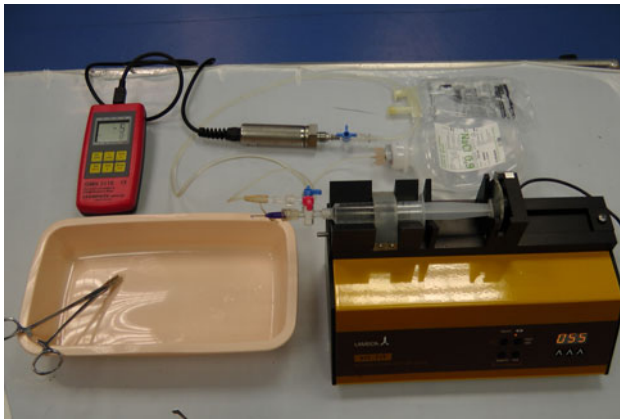
Fig. 1 Burst pressure measurement assembly

day 0 and on the day each pig was killed were compared using the Wilcoxon test for paired data.

## Results

### Clinical data

Clinical data are detailed in Table 1. In brief, there were no perioperative complications. All right carotid arteries were sealed and divided in 1.78 ± 0.4 s. There was no failure of hemostasis. Postoperative follow-up was uneventful and there was no secondary bleeding.

**Table 1** Clinical results

| Group | Day 0 Right carotid division | Days 1–7 Left carotid division | All | p |
|---|---|---|---|---|
| Pigs (n) | 26 | 26 | 26 | – |
| Arteries (n) | 26 | 26 | 52 | – |
| Operative complications | | | | |
| Preoperative hemorrhage | – | – | – | – |
| Neurologic | – | – | – | |
| Other | – | – | – | |
| Postoperative complications | | | | |
| General | – | NA | – | |
| Secondary bleeding | – | NA | – | |
| Sepsis | – | NA | – | |
| Other | – | NA | – | |
| Artery diameter | 5.31 ± 0.8 | 5.57 ± 0.7 | 5.44 ± 0.8 | ns |
| Division duration (seconds) | 1.78 ± 0.4 | 1.51 ± 0.3 | 1.74 ± 0.4 | ns |

NA not applicable, ns not significant

The second surgical procedure was also uneventful. All left carotid arteries were sealed and divided in 1.51 ± 0.3 s. Reopening the previous right cervicotomy did not result in any bleeding sequelae, unexpected inflammatory lesions, or other events. All distal and proximal parts of left and right divided carotid arteries were easily recognized and harvested. In total, 104 arteries' segments were analyzed.

### Measurements

The mean diameter of the arteries was 5.4 ± 0.8 mm. All measurements are detailed in Table 2. Burst pressure was always above 360 mmHg (Fig. 2) and was never below 500 mmHg in any group. It reached a median of 949 (IQR 781–1,181) at D0. Although, burst pressure always remained above 500 mmHg, there was a tendency toward a drop in postoperative vs. D0 burst pressure (Fig. 3). This drop was significant in groups D2 and D3 (Figs. 3, 4).

## Discussion

Our study is the first experimental study to demonstrate the efficacy and reliability of a vascular sealing device in the postoperative period. We measured burst pressure on arterial segments harvested several days after their section. We observed a median (IQR) burst pressure of 949 (781–1,181) mmHg on arteries immediately after sealing and division (D0). This value is in the high end of what we found in the literature: burst pressure measured after in vivo sealing in fact varied from 291 to 900 mmHg depending on the device used [13–16]. Higher values up to 1,800 mmHg are observed when noncirculating arteries are sealed in vitro [10]. In spite of the care taken by the authors to recreate conditions close to physiological conditions, these value differences mean that caution must be exercised when extrapolating these results for an in vivo situation.

We did not observe immediate failure of hemostasis with the device used. Our results compare favorably with those reported in the literature. The failure rate of the ultrasonic or electrical vascular devices tested varies between 10 and 20% [10]. These results could be explained on one hand by the fact that the THUNDERBEAT® integrates two types of optimized energies, ultrasound and bipolar. Moreover, vascular divisions have been realized by skilled practitioners using ultrasound or advanced bipolar devices for 15–20 years. Their mastery of these tools probably helped prevent failures of hemostasis.

Our experimental study was, to our knowledge, the first to obtain controlled values for postoperative burst pressures in a long-living model. These values remain high during

**Table 2** Burst pressure measurements

|  | Day 0 (LCA) | Sacrifice day (RCA) | p |
|---|---|---|---|
| Group 1 (day 0 vs. day 1) n = 6 Burst pressure mmHg (IQR) | 970 (810–1178) | 702 (598–827) | ns |
| Group 2 (day 0 vs. day 2) n = 4 Burst pressure mmHg (IQR) | 1,213 (936–1379) | 743 (665–811) | 0.02 |
| Group 3 (day 0 vs. day 3) n = 4 Burst pressure mmHg (IQR) | 1,133 (1,066–1,224) | 712 (646–904) | 0.008 |
| Group 4 (day 0 vs. day 4) n = 4 Burst pressure mmHg (IQR) | 875 (751–919) | 605 (568–854) | ns |
| Group 5 (day 0 vs. day 5) n = 4 Burst pressure mmHg (IQR) | 909 (786–999) | 656 (581–839) | ns |
| Group 6 (day 0 vs. day 7) n = 4 Burst pressure mmHg (IQR) | 760 (701–813) | 741 (671–1,330) | ns |
| All 26 D0 pigs—52 measurements of LCA | 949 (781–1,181) | – | – |

*LCA* left carotid artery, *RCA* right carotid artery



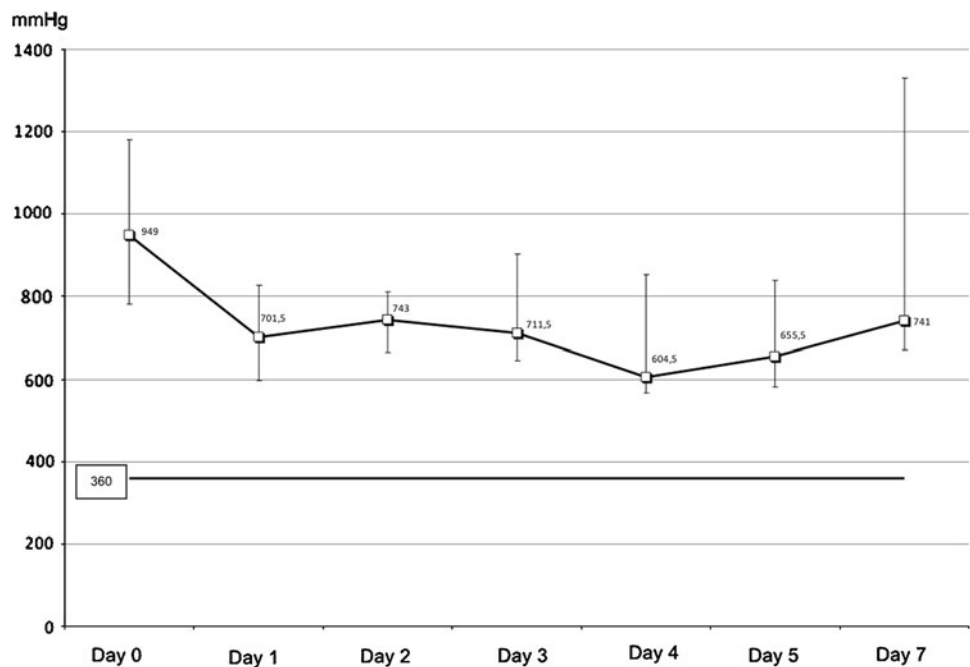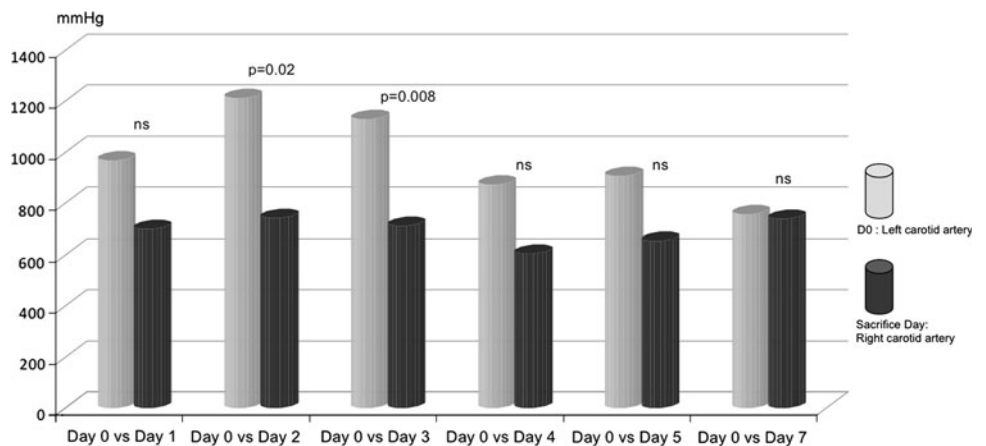**Fig. 2** Evolution of median (IQR) burst pressure over time



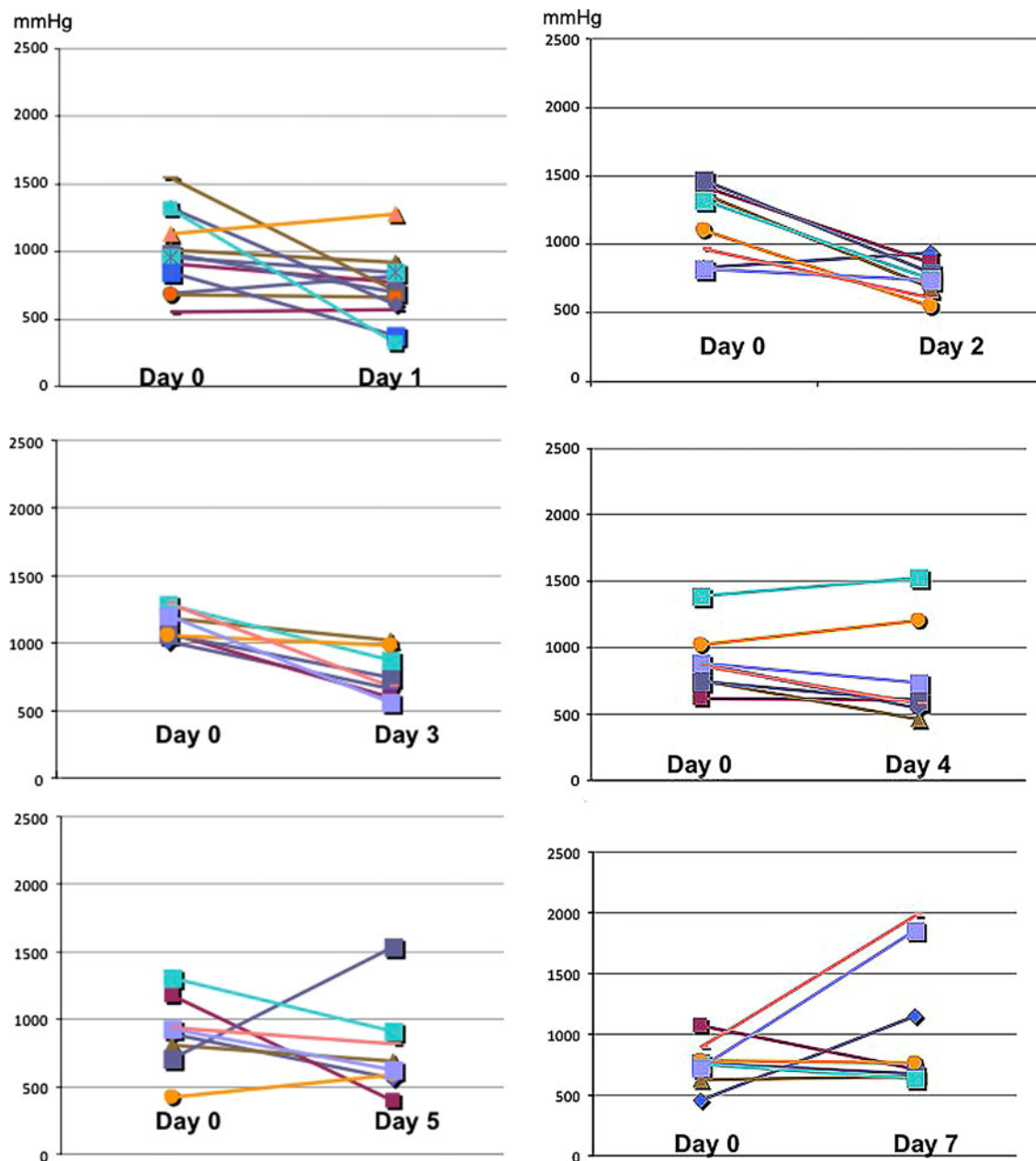**Fig. 3** Variations in median burst pressure in each group

Fig. 4 Variations in burst pressure in each group (individual results)

the first 7 postoperative days, not falling below 500 mmHg, i.e., more than four times the physiological blood pressure. We can, however, note that postoperative burst pressure is lower than that measured on day 0. Moreover, this decline is significant on D2 and D3. To our knowledge, such results have never been published. We know that during healing, tissue reorganization occurs around sealed vessels; in particular, it involves an area of necrosis [20]. Moreover, these symptoms reach a peak during the first postoperative week [21]. Our study thus questions the methods of preclinical testing of vascular sealing devices. It shows that a device

cannot be considered reliable based solely on immediate burst pressure data. In fact, we can question the fate of sealed vessels depending on the type of energy used or on the occasionally low initial level of burst pressure.

## Conclusion

THUNDERBEAT® is an effective device for sealing and cutting medium- to large-sized (>5 mm) arteries. Its safety is maintained during the first postoperative week. The

variations observed in the postoperative period mean that measurements of immediate burst pressure should not be the sole means of validating vascular sealing devices.

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